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High-Permeable Concrete with Drainage Effect: Analysis of the State and Prospects of Development

The subject of this work is a multi-criteria analysis of the status and technology development prospects for the production and use of highly permeable concrete with a drainage effect, to which are assigned materials with a permeability coefficient of at least 0.1 cm/s, provided with highly porous structure concrete without taking into account technological holes. Analysis of the results of experimental studies performed by both domestic and foreign authors in the last decade, and presented in an open peer-reviewed sources, allowed to structure highly permeable concretes on a functional purpose. Highlighted concrete for road and sidewalk coverings, filtration systems and drainage gutters, as well as decorative concrete with an organic plant layer, the so-called “green concretes”, which, in turn, are used for both horizontal and vertical engineering solutions, and characterized high architectural expressiveness. The accumulated empirical material made it possible to generalize and structure the available data according to criteria such as the type of binder used, the genetic type of rocks used to obtain coarse aggregate, and the type of functional additives. The analysis of the results of work on the development of rational compositions, increasing the drainage ability, strength, wear, frost and corrosion resistance, as well as studying the mechanism of clogging of through pores and the destruction of highly permeable concrete, is presented. Defined boundary values of porosity, strength, and water permeability coefficient for the concretes type under consideration depending on the functional purpose. The existing problems are identified and ways to increase the efficiency of highly permeable concrete with a draining effect are outlined.

Keywords: high permeability concrete, permeable concrete, permeable coating, drainage concrete, porous concrete, coarse aggregate, through pores, permeability coefficient, clogging mechanism.

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Высокопроницаемые бетоны с дренирующим эффектом: анализ состояния вопроса и перспективы развития

Предметом настоящей работы явился многокритериальный анализ состояния и перспектив развития технологий получения и применения высокопроницаемых бетонов с дренирующим эффектом, к которым отнесены материалы с коэффициентом проницаемости не ниже 0,1 см/с, обеспеченным высокопористой структурой бетона без учета технологических отверстий. Анализ результатов экспериментальных исследований, выполненных как отечественными, так и зарубежными авторами за последнее десятилетие и представленных в открытых рецензируемых источниках, позволил структурировать высокопроницаемые бетоны по функциональному назначению. Выделены бетоны для дорожных и тротуарных покрытий, систем фильтрации и дренажных водостоков, а также декоративные бетоны с органическим растительным слоем, так называемые «зеленые» бетоны, которые, в свою очередь, применяются как для горизонтальных, так и для вертикальных инженерных решений и характеризуются высокой архитектурной выразительностью. Накопленный эмпирический материал позволил провести обобщение и структурирование имеющихся данных по таким критериям, как вид применяемого вяжущего, генетический тип горных пород, используемых для получения крупного заполнителя, вид функциональных добавок. Представлен анализ результатов работ по разработке рациональных составов, повышению дренирующей способности, прочности, износо-, морозо- и коррозионной стойкости, а также изучению механизма засорения сквозных пор и разрушения высокопроницаемого бетона. Выведены граничные значения пористости, прочности и коэффициента водопроницаемости для рассматриваемого вида бетонов в зависимости от функционального назначения. Обозначены существующие проблемы и намечены пути повышения эффективности высокопроницаемых бетонов с дренирующим эффектом.

Ключевые слова: высокопроницаемый бетон, проницаемый бетон, проницаемое покрытие, дренажный бетон, пористый бетон, крупнозернистый заполнитель, сквозные поры, коэффициент проницаемости, механизм засорения.

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Nowadays the use of permeable concrete pavement and related studies increased due to its environmental friendliness, reduction of pollution and geothermal degree of the environment, the improvement of traffic safety conditions, especially during rainy days.

Due to the "frame – pore" structure and, as a result, high open through porosity, highly permeable concrete is characterized by a high filtration coefficient and enhanced drainage effect.

Highly permeable concrete is used in hydraulic engineering and road construction, in the creation of filters and drainage systems for the removal of melt and rain water from pavements, as well as in the installation of fasteners for earthworks and antimud facilities and other structures. In road construction, this type of concrete is used either as a supporting drainage layer, laid under the cover of a road and installed under a tiled floor or paving, or for the creation of parking lots, pedestrian and bicycle paths and other coatings with low traffic intensity. When necessary the structures of highly permeable concrete with a draining effect are reinforced, which makes them less susceptible to tensile forces.

The use of this kind of concrete eliminates the need to create storm collectors and communication modules, which reduces the cost of installing underground pipelines and storm drains, as well as their maintenance. Being a stable element of the urban drainage system, highly permeable concrete plays an important role in the reduction of local floods in urban areas, regulating the urban microclimate and maintaining the ecological balance [1].

A relatively new area of the use of highly permeable concrete, which is still not very common in Russia, is the creation on its basis of living concrete materials and systems [2–5]. They are aimed at the development of biophilic design in cities facing a changing climate and population compaction. Plant concrete [3–5] is an effective environmentally friendly material, which is increasingly used in the creation of architectural facades of buildings, sidewalks, car parks and embankments in order to reduce environmental pollution, control storm drains and prevent landslides. In comparison with existing living wall systems, light, "hanging like curtains on the building's façade", made of felt and plastic for example, the use of highly permeable concrete in the construction of living walls [2] helps to extend their life cycle and reduce cost by eliminating the secondary supporting structure and the possibility of integrating such walls into the structure of a building.

However, despite the possibility of the use of a wide range of applications of highly permeable concrete, due to sufficient deformation-strength, thermotechnical, sound insulating indicators and high fire resistance, the problem of extending the life of this material in connection with its operation in conditions where it is subjected to a superposition of corrosive attack, physical, chemical and biological factors, as well as reduced permeability due to clogging remains not solved. It is obvious that each type of impact leads to operational fatigue of the building material and has a significant impact on the final resistance and durability of structures during operation, therefore permeable concrete requires regular maintenance by vacuum treatment, pressure washing, etc. Aggressive operating conditions cause the need to assess the impact and take into account the contribution of each type of impact, both in the development of optimal compositions and in the operation of structures made of highly permeable concrete, which is an important task during the development of the methods for resistance and stability prolongation.

Results of Published Data Analysis

Issues of definition

In the course of the search and analysis of scientific literature, the divergence in interpretation were identified in understanding the key definition for the description of highly permeable concrete with a draining effect, and therefore, it is necessary to dwell on the issues of definition. To describe this type of concrete, scientists from different countries use the following terms: permeable [6–53], drainage [54, 55], high permeability [56], water permeable [57], porous concrete [58–69], living [2, 4], plant [3, 5], etc. The search of sources with all of the above terms was carried.

According to SP 28.13330.2017 [70], there is a classification of concrete by permeability, according to which the maximum values of the filtration coefficient ($2–7\times10^{-9}$/s) correspond to the concrete grade W4 of normal permeability. At the same time, according to the analysis of scientific literature, as well as regulatory documents of enterprises, concrete with a draining effect should have a throughput of at least 0.1 cm/s. In this regard, we can not refer drainage concrete to materials with "normal permeability" or to call it simply permeable, despite the existing classification. Therefore, we use the concept of highly permeable concrete.

The concept of permeable or drainage concrete is also understood as the creation of structural solutions for road surfaces and slabs, obtained on the basis of coarse or fine-grained, dense or cellular concrete with the creation of service holes. Thus, in one of the analyzed works [7], the concept of permeable concrete was applied to porous concrete with technologically created through open pores, which fundamentally distinguishes this material from the rest. This work was included in the selection of articles, since it met the requirements for it. However, it is not correct to refer such material to permeable concrete, therefore, similar design solutions were not considered in this article when analyzing the compositions and technology of material production.

Despite the fact that there are many publications on the creation and use of highly permeable concrete [1–53, 71–73], a number of unresolved issues remain related to the low strength and durability of materials. In order to generalize the research results, identify the applied technological solutions and their influence on the properties of the obtained highly permeable materials, the proposed analysis of scientific publications seems is very relevant.

Thus, the subject of this article is the analysis of literary sources that consider the development of concrete with a permeability coefficient of at least 0.1 cm/s, provided with a highly porous concrete structure without taking into account service holes that are used as the top layer of the structural solution in road construction, filtration systems and drainage gutters, as well as decorative materials and systems with an organic plant layer.

Analysis of the dynamics of publication activity

During the analysis we selected the articles published in leading peer-reviewed Russian and international issues that were publicly available for the period for the period 2010–2020. In total we analyzed 76 scientific papers. This number did not include the works of a theoretical and review nature, materials from forums and conferences, texts of dissertations and monographs, articles that are in private or limited access, and summary research.

The analysis of publication activity was carried out on the basis of several factors, such as: the number of publications for a given period (Fig. 1), the involvement of scientific schools in different countries (Fig. 2), climatic conditions for the study of this kind of concrete.

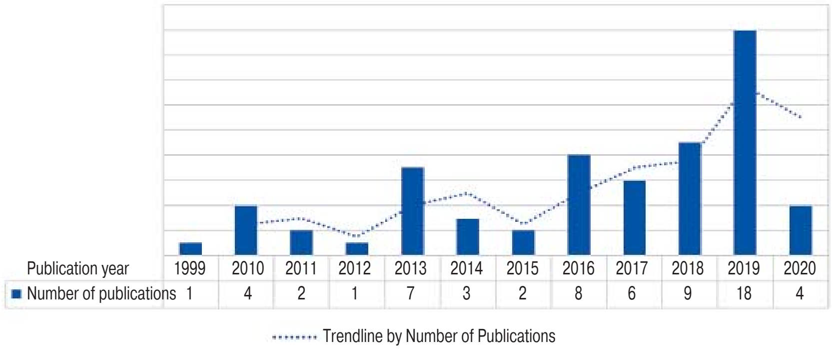

Fig. 1. The dynamics of publication activity

Рис. 1. Динамика публикационной активности

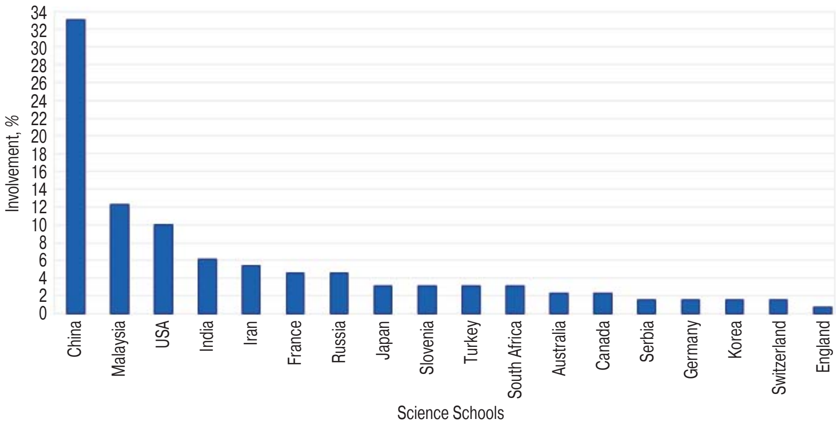

Fig. 2. Russian and foreign scientific schools that study highly permeable concrete with a draining effect

Рис. 2. Российские и зарубежные научные школы, занимающиеся исследованием высокопроницаемого бетона с дренирующим эффектом

During the ranking of articles according to the number of publications for a given period (Fig. 1), it was revealed that interest in the research topic has a pronounced growth. To date, the peak of publication activity is in 2019, but the number of articles in the first two months of 2020 is 22 of those published last year. This suggests the excess in indicator of 2019.

Fundamental and applied research in the field of development of highly permeable concrete is carried out by both Russian and foreign scientific schools (Fig. 2). The attempts to implement the research results with access to industrial testing of technologies also remain the prerogative of foreign researchers to a greater extent. The leading positions in the study of highly permeable concrete with a drainage effect are occupied by scientists from China, Malaysia, the USA and India.

Probably, the leadership of these scientific schools is explained by the need to solve practical problems relevant to their respective climatic zones, associated with increased amount of precipitation and air temperature that rarely drops below 0°C.

Thus, in the subtropical climatic zone (the USA, the Northern China), subtropical cyclones predominate, and precipitation occurs in the cold period, when the air masses move towards the equator. The subequatorial climatic zone (India, the Southern China) in the summer is influenced by equatorial moist winds, in the winter – by trade winds. The closer to the equator, the more it rains. The equatorial climate (Malaysia) remains virtually unchanged throughout the year. Temperature does not fall below + 27°C. Due to heavy rainfall, high humidity, fog and cloudiness are formed.

Thus, there is a correlation between the interest of scientific schools involved in the study of highly permeable concrete with a draining effect and their belonging to certain climatic zones. At the same time, in recent years, the increase in the number of publications in which the results of studies on the development of compositions and the study of the properties of such a variety of concrete, design solutions for the use of products from high-permeable concrete and the expansion of their use from drainage concrete for road surfaces to the so-called “Green” concrete, indicates the interest and demand for this type of composite materials in construction.

Analysis of the results of experimental studies

The analysis of publications revealed that it was impossible to specify the data on the properties of raw materials and developed concrete to uniform quality indicators, in view of the different presentation of information by the authors, which was reflected in the structured information of Table 1, as well as the absence of a number of physical and mechanical properties, which did not allow the inclusion of the results of these articles in statistical processing. On the one hand, this makes it difficult to generalize and establish the laws of the properties of the developed materials on the type and characteristics of raw materials, and on the other, it allows expanding the range of possible methods for the assessment of properties and controlled parameters.

For example, the authors of the works [1, 11, 40, 44, 45] touched upon the issue of forecasting, as well as increasing the permeability and strength of studied material. A distinctive feature of the studies [6, 66] is the search for methods to eliminate of through pores clogging of highly permeable concrete material and the analysis of the mechanism of their clogging. In the works [37, 69] the results of the studies of destruction mechanisms of permeable concrete are presented; the articles [28, 31, 47, 49, 50, 57, 58, 74] present the assessment of filtration ability; the authors of publications [13, 38, 51] pay their attention to the influence of the thickness of cement paste on the characteristics of highly permeable concrete. For convenient information perception, when describing the results of the studies of various authors on the graphs and in text, we gave references not only to the source of information, but also to the sample number indicated in the first column of Table 1.

The analysis of the results of experimental studies (Table 1) [1–5, 8–17, 19–38, 40–48, 54–65, 67–69, 75, 76, 78, 79, 84] allowed structuring publications on the topic of highly permeable concrete with a draining effect according to the following criteria.

– By composition:

1. Based on cement without using a polymer binder
2. Based on cement using a polymer binder.
3. Based on a polymer or organo-polymer binder.

– According to the functional purpose:

1. Concrete for road and pavement.
2. Concrete for filtration systems and drains.
3. Decorative concrete with an organic plant layer.

A distinctive feature of mixtures for highly permeable concrete is the absence or minimum amount of fine aggregate, which provides a large-pore structure. The most commonly used binder is Portland cement, rarely bitumen. This is largely due to the fact that cement concrete pavements have a higher degree of reflection than asphalt concrete pavements, which means that they prevent the temperature rise of the urban pavement in summer and can save up to 31% of the cost of energy and maintenance spent on lighting these pavements.

Following the steady trend of recent decades in the direction of resource reduction and energy consumption of building materials industry, in order to reduce the binder consumption while maintaining its performance characteristics when designing highly permeable concrete, industrial wastes are used as active mineral additives (pyrogenic – fly ash, slag; mechanogenic – highly dispersed rock crushing fines). Depending on the method (separate introduction or joint grinding) and the amount of introduction, the authors consider this as the use of mineral additives [3, 11, 12, 15, 24, 25, 31, 56, 65, 75, 76] or as the preparation of a composite inorganic binder [13, 16, 21, 57, 61, 69]. A separate layer of work is associated with the use of sulfoaluminate cement (fast-hydrating) [4, 5], slag Portland cement [57] and pozzolanic cement [61] (sulfate-resistant), phosphate-magnesium cement (quick-hardening) [16] as a binder.

In view of the need to increase the water and frost resistance of highly permeable concrete and their mechanical properties, a number of works are based on the use of polymer binders, such as polyester resins [17], emulsions of ethylene vinyl acetate [35] and latex [64], silane polymer [9] as part of a raw material mixture, styrene-butadiene-styrene [7, 20, 46, 58–62, 64, 67]. Moreover, their content varies from 3.2% by weight of cement [34], which can be considered as an additive, to a "cement: polymer binder" ratio of 2: 1 [62], which corresponds to the concept of a composite organo-mineral binder. However, the high cost of polymers and the viscosity of some of them, for example, epoxy resin, as well as their sensitivity to open flame and elevated temperature, lead to the limit of their use, difficulties in mixing the components and destruction of the material, respectively. In this regard, the use of low cost polymer binder options, such as polyester resins, is recommended.

The optimum range of water-cement ratio in terms of strength and permeability is from 0.30 to 0.38, however, the increase in the content of cement paste can cause local clogging, segregation of cement and a decrease in permeability, leading to the formation of concrete with a low filtration capacity, despite the high porosity [11, 13, 52, 77].

The aggregates in highly permeable concrete with a draining effect have a uniform or narrow fraction, mainly from 4.75 to 19.5 mm, which allows creating larger pores and improve permeability. Fine aggregate, as a rule, is excluded from permeable concrete, but the addition of a small amount (up to 7% of the mass of large aggregate) increases strength, density and frost resistance, while maintaining sufficient water throughput. The use of aggregates with high water absorption or low density leads to the decrease in frost resistance of concrete [14].

Most often, limestone aggregate is used in the analyzed works [2, 3, 10, 13, 30, 31, 33–35, 38, 45–47, 65], granite is used but less frequently [12, 23, 27 , 36, 62, 64, 76, 78], we also found the publications on the use of basalt [1, 15, 25, 58], pumice [22, 30], expanded clay [4, 11], quarry stone [79], diabase [65], sandstone [59] (Fig. 3). This can be explained firstly, by the maximum use of local raw materials. Secondly, even with the presence of crushed stone from strong igneous or metamorphic rocks, the preference may be given to less strong carbonate rocks, which is associated with the absence of the need to use crushed stones of higher grades for road pavements with low throughput.

In the absence of the need to obtain high-quality concrete, quite often secondary products and industrial waste are introduced into the concrete mixture for highly permeable concrete in the form of aggregate or its component [80]: crushed concrete screenings [25–27, 62], construction waste [5, 9 , 57], glass fragments [19, 26], rubber crumbs [42, 56, 67], ceramic brick waste [25], palm oil production waste [33, 36], slag waste [14, 16, 40], etc. However, the excess of certain quantitative values of the input waste leads to a noticeable decrease in the strength of concrete, which limits their use.

The researchers note that despite the fact that mixing aggregates of different fractions improves mechanical properties, there is a decrease in porosity and filtration rate, which negatively affects highly permeable concrete. Rounded aggregate, such as gravel, pebbles, creates a denser packing, reducing porosity. Flaky placing in the same plane during compaction, also increases density, and also negatively affects the contact area and monolithization by binders [6, 9].

In order to improve the physic-mechanical properties of highly permeable concrete with a draining effect, as well as to improve the quality of other types of concrete [81, 82], micro-reinforcing additives such as basalt [1], polypropylene [35] and fiberglass [43, 57] and also nanomaterials as nanosilica [21, 55, 56] and nanoferrous [31] are used. The use of nanomaterials allows increasing strength, but the high cost of such components makes their use difficult [83].

Various functional additives are actively used. For example, plasticizers [2, 10–15, 21, 22, 24, 34–37, 40, 43, 48, 57, 60, 63, 68, 69, 76, 84] increase the mobility of the mixture at a constant amount of water; set retarders [4, 47] increase the efficiency of the mixture by reducing the rate of cement hydration. Thickeners [20]; water reducing additives [3, 4, 20, 31, 45, 55, 75]; viscosity modifiers increasing the uniformity of the mixture and preventing the depletion of cement paste and air-entraining additives increasing the frost resistance of the cement matrix [37, 45] are also used. This group of additives also includes absorbing components that favorably affect the adhesive ability of highly permeable concrete, helping to improve the moisture resistance of the mixture and remove impurities, while lowering the pH of the filtered liquid (sample 68, 72) [57, 58].

It is necessary to note that in most works [2, 4, 5, 8, 11, 12, 15, 20, 24, 28, 32, 42, 45, 58–60, 65, 67, 68], the functional properties of drainage concrete are studied, however, their numerical values are not given in the text of the articles.

Analyzing the operational properties of highly permeable concrete, we can say that the porosity of products from such concrete (Fig. 4) varies in the range from 12.4 to 38% and depends on the type of aggregates and compaction method, the average porosity of the analyzed samples is as follows:

– for road and pavements surfaces – 23.5%;

– for filtration systems and drainage systems – 21.4%;

– decorative concrete with an organic plant layer – 31.4%.

At the same time, the lower boundaries of the average values of porosity are 15.7%, 14.2%, and 20.9%, respectively, and the upper ones are 31.4%, 28.5%, 41.9%. 52 samples out of 63 fell into the zone of average values, 5 samples were in the zone below the average (sample numbers in the table are 8, 17, 45, 54, 62), however, their porosity is not much lower than average.

The compressive strength (Fig. 5) ranges from 5.7 to 73.9 MPa, the average values of the strength of the samples are 21.8 MPa, the lower limit of the average values of strength is as follows:

– for road and pavement surfaces – 22.7 MPa;

– for filtration systems and drainage systems – 13.0 MPa;

– decorative concrete with an organic plant layer – 10.2 MPa.

The upper boundaries of the average strength values are 30.2 MPa, 17.3 MPa, and 13.7 MPa, respectively. 35 out of 64 samples fell into the zone of average values; 17 samples were below the average. In some cases (sample numbers in the table are 7, 8, 19, 50, 51, 67), the strength indicators are significantly higher than the others.

The cement paste in permeable concrete is a very thin layer that binds the coarse aggregate particles together. If durable aggregate is used, porous concrete tends to collapse at the boundary line between cement stone and aggregate [85] and this leads to low compressive strength. In this regard, they strive to increase the adhesion of the binder to the aggregate, which is ensured by heteroepitaxial growth of cement hydration products on the surface of the aggregate, which acts as a substrate for crystallization of new growths [14].

The permeability coefficient of such concrete (Fig. 6) varies from 0.1 to 3.9 cm / s, the average values of sample permeability is as follows:

– for road and pavement surfaces – 1.0 cm/s;

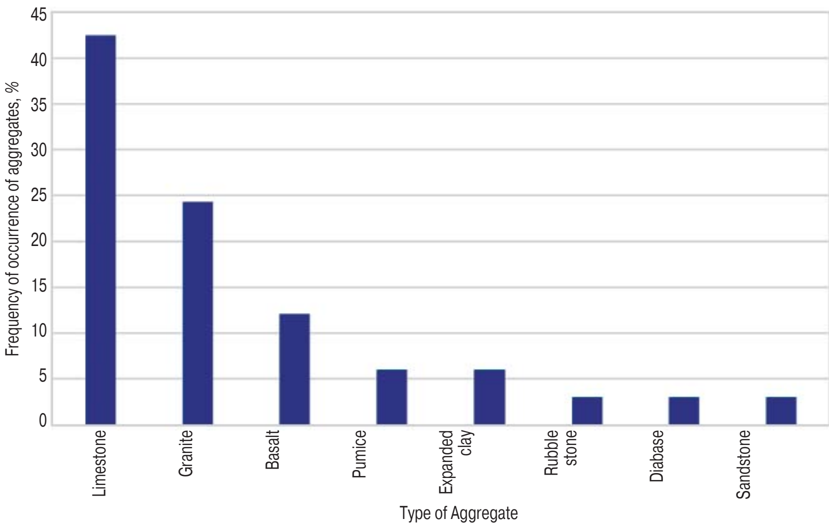

Fig. 3. The frequency of use of various types of coarse aggregate in highly permeable concrete

Рис. 3. Частота использования различных видов крупного заполнителя в высокопроницаемых бетонах

– for filtration systems and drainage systems – 1.7 cm/s;

– decorative concrete with an organic plant layer – 2.8 cm/s.

22 of 58 samples belong to the zone of average values (from 0.7, 1.1, 1.9 to 1.4, 2.2, 3.9 cm / s, respectively), 13 samples (sample numbers in the table are 14, 26, 29, 30, 33–36, 55, 63–65, 77) are characterized by increased drainage ability.

Highly permeable concrete with a draining effect, regardless of the functional purpose, is characterized by high porosity, as a rule, from 15%, water permeability – from 0.1 cm/s, significant absorption of noise and ambient temperature due to the porous structure of the material and its drainage ability. However, one of the negative factors affecting the efficiency of the use of such concrete is material degradation caused by temperature extremes (transitions through the zero mark), physical and biological clogging of the pore space, chemical and biocorrosion, and low strength.

To sum up the analyzed information from the point of view of the various functional purposes of highly permeable concrete, we distinguished the following distinctive features in terms of composition, requirements and operation.

Permeable concrete used in sidewalk construction has lower strength and durability compared to other types of pavements due to the presence of high porosity, which limits its use in places with high traffic density [82].

For concretes intended for single-layer or top layers of two-layer road pavements with a traffic intensity of 200–6000 units/day, the minimum required design class of concrete in compressive strength is B25 [86], the average strength should be at least 32 MPa, highly permeable concrete with strength below normal can be used for the pavements with low traffic intensity (sample number in table 1–69).

Highly permeable concrete for filtration and drainage systems (sample number in table 70–74) differ from other materials in their functional purpose because of their higher resistance to aggressive environmental influences, lower strength (10–16 MPa) and porosity (15.5–25%), but with increased filtration capacity in relation to highly permeable concrete for road and sidewalk pavements.

As a rule, rainwater and groundwater contain fragments of heavy metals, permeable concrete for filtration and drainage systems allow water to pass through the thickness of the material, absorbing and binding heavy metals in groundwater.

One of the most promising alternatives to traditional filters is the passive treatment of contaminated water with the use of highly permeable reactive barriers derived from concrete products. These barriers are designed to remove heavy metals dissolved in water and its acid reduction [11, 12, 57]. Therefore, a separate technological task is the required regular care to restore filtration ability.

For example, the authors of the work [11] showed the possibility of the use of highly permeable concrete as a reactive barrier for water purification, removal of cadmium and Cd (II) ions using the chelation properties of thiocyanate. For this purpose, fly ash granules modified with 3-thiocyanatopropyltriethoxysilane are introduced into the concrete mixture, which allows sequestering heavy metals through the thiocyanate group.

It was found that the removal efficiencies of Al, Fe, Mn, Co, and Ni were 75%, 98%, 99%, 94%, and 95%, respectively, and a highly permeable reactive barrier can reduce water acidity (pH) [12]. The high degree of acid reduction and removal of metals by permeable concrete is explained by the dissolution of its component, portlandite. The mechanism for the removal of metals from water is the deposition of metal hydroxides.

In one of the works [57], the effect of accelerated carbonization and hydraulic delay time on the removal of lead (Pb) in a permeable concrete filter is studied. Accelerated carbonization technology suppresses the increase in the alkalinity of a solution, regardless of its initial pH, however, it increases the degree of calcium leaching. Therefore, the cost of such a filter increases. However, the time and materials required to process 1000 liters of a solution containing 8 mg Pb in an amount of 84 mg/L with an efficiency of 84% are calculated as 36 hours and 3127 euros, which is quite inexpensive in contrast to the currently used treatment facilities. In this regard, it is recommended to install pre-treatment blocks, that is, sand filters in front of a layer of highly permeable concrete, due to which it is possible to reduce the frequency of filter maintenance, the use of concrete waste (recycled aggregate) to reduce costs in the preparation of highly permeable concrete.

As it is mentioned above, highly permeable concrete, used in combination with plant objects, is not yet so common in the architectural design of many countries, including Russia. Decorative concretes with an organic plant layer are called “living” and “plant concrete” (sample numbers 75–78) [2–5]. There are several options for their realization:

– decorative “living” walls [2], vertically cast using standard formwork;

– retaining “living” walls [4, 5], designed to protect slopes along roads and river banks;

– “living” plates [3], a kind of grass lawn cover.

The specificity of this type of concrete is the use of mineral components, such as biochar [3], which improves the germination of plant seeds in the concrete mix.

Special attention in the assessment of the operational properties of such varieties of concrete is paid to the chemical composition of the irrigation water passing through the concrete, the measurement of its pH and the rate of release of nitrogen and phosphorus (the release of fertilizers from plant concrete), as well as the adhesion of the layer of permeable concrete to the supporting part of the structure.

The service life of highly permeable concrete with a draining effect ranges from 6 to 20 years. The authors studying the effectiveness of the use of permeable concrete coatings note that with a high demand for this kind of material and a number of its advantages, the question of

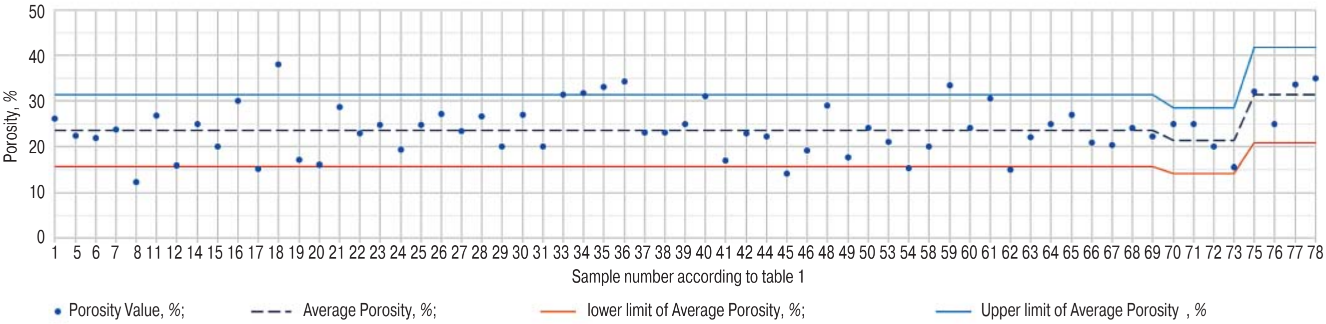

Fig. 4. Porosity of highly permeable concrete samples
Рис. 4. Пористость образцов высокопроницаемого бетона

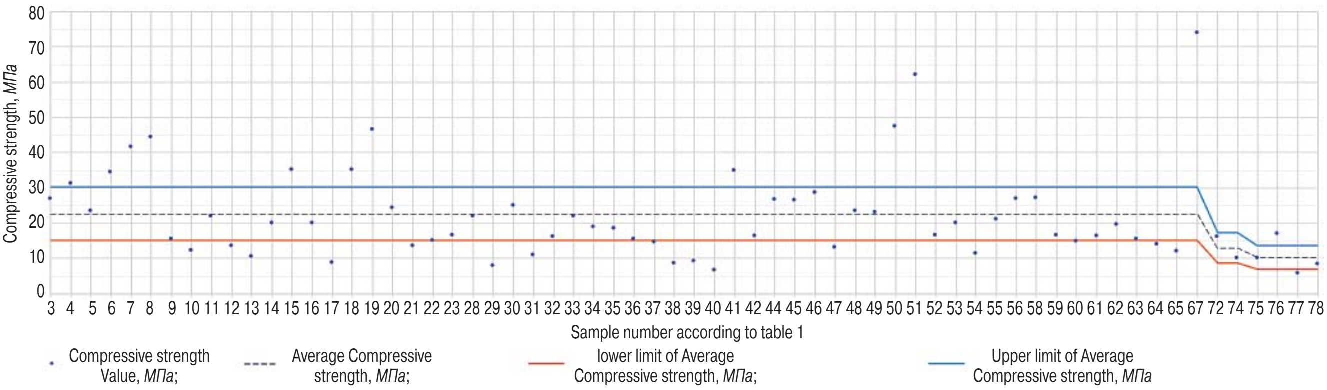

Fig. 5. Strength of highly permeable concrete samples
Рис. 5. Прочность образцов высокопроницаемого бетона

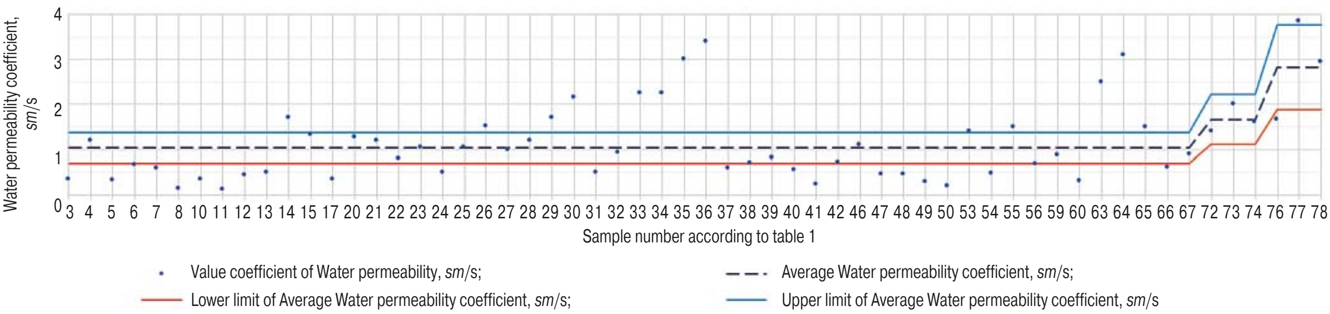

Fig. 6. Water permeability coefficient of highly permeable concrete samples
Рис. 6. Коэффициент водопроницаемости образцов высокопроницаемого бетона

susceptibility to clogging, leading to problems with serviceability and premature degradation, is still open.

Physical clogging can be caused by the accumulation of waste on the surface and in the structure of the pores. This is probably the most common mechanism.

As well as ordinary concrete, the degradation of permeable concrete during freezing-melting increases with a higher degree of saturation of the pore space with water. However, voids can provide some resistance to destruction provided that they are emptied before freezing. Therefore, it is recommended to place a highly permeable coating over the drained base and minimize the accumulation of free water in the thickness of concrete.

Biological clogging occurs due to the penetration of plant roots, the germination of algae and bacteria. The tasks associated with the increase of the biostability of concrete can be solved by the use of a set of measures in which, we should take into account the prospects for the use of active components [87, 88], as well as the possibility of bacterial biomineralization in addition to traditional materials science solutions.

Thus, the analysis of the results of experimental studies performed by both national and foreign authors allowed structuring highly permeable concrete for its functional purpose. On the basis of this structuring we distinguished concrete for road and pavement surfaces, filtration and drainage systems, as well as decorative concrete with an organic plant layer, which, in turn, are used for both horizontal and vertical engineering solutions and characterized by high architectural expressiveness. Another ranking criterion was the type of binder – concrete based on cement, polymer or organo-polymer, and also on composite organo-mineral binder. By the type of mineral raw materials, which is used as a large aggregate, Highly permeable concrete with drainage effect

No.	Concrete composition: Types of Binder	Concrete composition: Type of aggregate	Concrete composition: Functional Additives	Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
1. CONCRETE FOR ROAD COATINGS AND PAVEMENT								
1.1. Based on cement without the use of a Polymer binder								
1	Portland Cement ρ=3150 kg/m^3	Aggregate fraction – 5–13 mm ρ=2730 kg/m^3	–	w/c=0,35 Concrete composition, kg/m^3: Cement – 253 Aggregate – 1554 Water – 88,6	– A constant water permeability in the saturated state with varying values of hydraulic gradient (Japanese Concrete Institute method (JCI)); – Porosity (P); – Non-linear water permeability index; – Horizontal and vertical water permeability.	P=26,2 %	The limitations of Darcy's law with respect to permeable concrete are proved.	[8]
2	Portland Cement R_c= 42,5 MPa	Crushed concrete and clay brick from demolition waste fraction – 5–10 mm CWi=26 % ρ_b=1220 kg/m^3 ρ_a=2530 kg/m^3	–	w/c=0,34 a/c=3,0 Concrete composition, kg/m^3: Cement – 464 Aggregate – 1392 Water – 157,76	– Membrane-forming ability for measuring the thickness of cement paste adhered to the surface of the aggregate (τ – is the ratio of the mass of stable cement paste on the aggregate surface to the mass of aggregate in the dry state, (MPT– is the maximum paste thickness of the paste coated on the aggregate surface); – Connected porosity with drainage method (CJJ/T 252-2016); – Density (ρ); – Apparent (ρ_a) and Bulk (ρ_b) density; – Crush index (CWi); – Water absorption (W); – X-ray micro-tomography.	ρ=1420 kg/m^3 W=3,75 % τ=0,288 MPT =0,29 mm		[9]
3	Portland Cement ρ=3085 kg/m^3	Sifted limestone (Jiangning quarry, China) fraction – 7,5 mm ρ_b=1453 kg/m^3 ρ_a=2778 kg/m^3	Superplasticizer PCA-1 (Subote Company, China)	w/c=0,375 a/c=4,0	– The chemical and physical properties of the cement (standard Specifications GB175-2007); – Compressive strength (R_c);	k=0,35 cm/s R_c=27,0 MPa	–	[10]

No.	Concrete composition: Types of Binder	Type of aggregate	Functional Additives	Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
					– Coefficient of water permeability (k); – Apparent density.			
4	Portland Cement type II	Limestone gravels fraction – 8–11,2 mm	Ground granulated blast-furnace slag (GBFS); Silica fume (SF); Polycarboxylic acid superplasticizer (SP) with a solid content of 15%	w/c=0,22 Mixture of cement paste components, %: Portland Cement – 60 GBFS – 35 SF – 5 SP – 1,45	– Strength and Coefficient of water permeability; – Shear stress and viscosity; – Rheological properties of cement paste.	k=1,19 cm/s R: 7 days=26 MPa 28 days=31,2 MPa Shear stress – 62,1 Pa Viscosity – 1,674 Pa×s	–	[13]
5	Portland Cement type I	Crushed Dolomite (coarse and 1,16–4,75 mm) ρ_b=1474 kg/m^3; Air-cooling copper slag ρ_b=2164 kg/m^3	Superplasticizer of Polycarboxylate Ether ρ = 1130 kg/m^3	w/c=0,3 Concrete composition, kg/m^3: Cement – 340 Water – 102 Superplasticizer – 1,7 Coarse aggregate: Dolomite – 456 Copper slag – 971 Shallow aggregate (Dolomite) – 340	– Physical properties of copper slag and dolomite aggregate (Water absorption, Bulk Density, LA abrasion value, Aggregate Crushing value); – Chemical composition of coarse aggregates; – Compressive and Bending (R_b) Strength (ASTM C496); – Density, Porosity and Coefficient of water permeability; – Adhesion (A) procedure described by ASTM C1583.	ρ=2340 kg/m^3 P=22,42 % k=0,336 cm/s R_c=23,45 MPa R_b=3,76 MPa A=3,01 MPa	–	[14]
6	Portland Cement (strength grade: 42.5)	Basalt fraction – 2,36–4,75 mm 4,75–9,5 mm 9,5–13,2 mm	Silica fume (SF); Superplasticizer SBT-PRC-I; Fly ash (FA)	w/c=0,31 a/c=0,22 Concrete composition, %: Fly ash – 20 Aggregate, %: 9,5–13,2 mm – 45 4,75–9,5 mm – 25 2,36–4,75 mm – 30	– Purification effect; – Porosity; – Coefficient of water permeability (GJJ / T 132-2009); – Alkali precipitation test.	P=21,8 % k=0,67 cm/s R_c=34,5 MPa	–	[15]
7	Magnesium Phosphate	Steel slag (SSA) fraction – 5–10 mm	Burnt magnesium (M);	SSA/MPC=4,8 B/MPC=0,16	– Crush index;	P=23,8 % k=0,585 cm/s	Methods adopted in this	[16]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
	Cement (MPC)	ρ=1750 kg/m^3 CWi=7,8 %	Metakaolin (MK); Ammonium dihydrogen phosphate (P); Borax (B); Dispersant (D)	Concrete composition, %: M – 3 P – 1 MK – 1 B – 0,15 D – 0,15	– Porosity and Coefficient of water permeability; – Compressive and Bending Strength.	R_c: 1 hour=17 MPa 1 day=34,5 MPa 28 days=41,5 MPa R_b=8,0 MPa	study were as follows: 1) Tamping molding method (into three layers, tamped 20–30 times), the tamping should be done in a spiral way, tamping rod should penetrate the upper layer about 20 mm; 2) Vibration molding method; 3) Hydrostatic molding method	
8	Portland Cement (strength grade: 42.5)	Basalt fraction –2,36–4,75 mm, 4,75–9,5 mm, 9,5–13,2 mm ρ_a=2465 kg/m^3 ρ_{cp}=1919 kg/m^3	Basalt fiber	w/c=0,25 a/c=0,24 Concrete composition, %: Aggregate: 9,5–13,2 mm – 10 4,75–9,5 mm – 70 2,36–4,75 mm – 20 Basalt fiber – 2	– Coefficient of water permeability; – Apparent density and Compact packing density (ρ_{cp}); – Strength and Porosity.	P=12,4 % k=0,138 cm/s R_c: 7 days=29,2 MPa 28 days=44,3 MPa	–	[1]
9	Portland Cement	Limestone and Gravel fraction – 10–25 mm ρ_a=2780 kg/m^3 CWi=8,5 %	Slag ρ=2890 kg/m^3; Fly ash; Polycarboxylic superplasticizer	Concrete composition, kg/m^3: Cement – 216,7 Water – 85,56 Aggregate – 1599,84 Fly ash – 26 Blast furnace slag – 52 Superplasticizer – 1,45	– Apparent density; – Crush index; – Strength; – Numerical simulation, the failure mode of porous concrete was analysed.	R_c=15,5 MPa	–	[69]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
10	Portland Cement PC II (OPC)	Gravel fraction – 5–15 mm; Coal gangue; Sand	Fly ash; Water-reducing admixture AE-d	w/c=0,3 Concrete composition, kg/m^3: Cement – 450 Water – 150 Gravel – 1080 Fly ash – 50 Sand – 250 Coal gangue – 460	– Density; – Coefficient of water permeability; – Compressive strength with constant pressure head method, the head pressure is 10 cm.	ρ=2244,8 kg/m^3 k=0,35 cm/s R_c=12,31 MPa	–	[75]
11	Portland Cement ASTM type I (OPC) R_c= 52,5 MPa	Waste glass cullet fraction – 2,36–5 mm; Recycled concrete aggregate fraction – 5–10 mm ρ_b=1335 kg/m^3	Silica fume (SF)	w/c=0,4 Concrete composition, kg/m^3: Cement – 272 SF – 30 Waste glass cullet – 755 Recycled concrete aggregate – 755	– Coefficient of water permeability and Water absorption (JIS A 5371-2016); – Thermal conductivit (λ); – Density, Strength and Porosity; – The pore structure distribution features on the two-dimensional images.	ρ=1932 kg/m^3 P=26,8 % k=0,12 cm/s R_c=22 MPa W=3,13 % λ=0,63 W/mK Pore distribution=2,06 6 mm	Permeable concrete blocks for pedestrian pavers	[19]
12	Portland Cement type I (OPC)	Aggregate fraction maximum nominal size of 10 mm W=0,46 % ρ=2560 kg/m^3	Fly ash (FA) class F with SiO_2, Al_2O_3, Fe_2O_3 – more than 70 %; Superplasticizer (SP); Nanosilica (NS)	w/c=0,3 c/a=0,466 Concrete composition, kg/m^3: Cement – 250 FA – 224,78 Aggregate – 1672 NS – 11,416 SP – 6 Water – 142,43	– Flow value workability of the cementitious paste (ASTM C230-03); – The setting time of cement paste; – Microstructure of cement stone; – Strength and Porosity; Coefficient of water permeability (by Yang and Jiang); – Filtration rate (k_f) by ASTM C1701-09.	P=15,96 % k=0,435 cm/s R_c=13,5 MPa k_f= 1,265×10^5 m/days Cumulative Pore Volume =213 mm^3/g Flow Value – 180 mm Setting Time – 240 мин	–	[21]
13	Portland Cement	Pumice fraction – 2,5 mm	Polycarboxylic Acid Superplasticizer; Silica fume	Concrete composition, %: Cement – 1 Silica fume – 0,5 Pumice – 2,5 Superplasticizer – 0,036 Water – 0,22	– Coefficient of water permeability; – Strength.	k=0,5 cm/s R_c=10,42 MPa	–	[22]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
14	Portland Cement	Aggregate fraction – 4,8–9,5 mm	Superplasticizer	a/c=4,76 w/c=0,3 Concrete composition, kg/m^3: Cement – 341,37 Aggregate – 1507,73	– Skid resistance by British Pendulum Test – Sound absorption (AC); – Compressive and Bending strength; – Porosity and Coefficient of water permeability; – The albedo coefficient (the Urban Heat Island (UHI) effect).	P=25 % k=1,74 cm/s R_c=20 MPa R_b=2,0 MPa AC=0,4 The albedo coefficient =0,29	–	[60]
15	Cement	Aggregate fraction – 4,75 mm	Silica fume; Nanosilica; Water-reducing admixture	w/c=0,2 a/c=4,5 Concrete composition, kg/m^3: Cement – 320 Aggregate –1440 Water – 64 Silica fume – 80 Nanosilica – 80 Water-reducing admixture – 11,52	– Compressive and Bending strength; – Porosity, Density и Coefficient of water permeability.	ρ=1800 kg/m^3 P=20 % k=1,32 cm/s R_c=35 MPa R_b=3,8 MPa	–	[55]
16	Portland Cement R_c=42,5 MPa	Granite Gravel fraction – 5–10 mm	–	w/c=0,35 Concrete composition, kg/m^3: Cement – 149 Aggregate –1917 Water – 55	– Compressive and Bending strength; – Porosity.	P=30 % R_c=19,97 MPa R_b=1,93 MPa	–	[23]
17	Portland Cement type I (OPC)	Aggregate fraction – 10 mm ρ=2560 kg/m^3; Rubber crumb fraction – 0,425–4,75 mm	Fly ash class F (FA); Nanosilica (NS)	w/c=0,3 c/a=0,382 Concrete composition, kg/m^3: FA – 90 NS – 6 Cement – 210 Water – 91,8 Rubber crumb – 20,83	– Coefficient of water permeability by ASTM 230-03; – Compressive strength and Porosity.	P=15,25 % k=0,344 cm/s R_c=8,81 MPa	–	[56]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
				Coarse aggregate – 1041,36				
18	Cement	Crushed stone (rubble stone) fraction –20–40 mm ρ=2160 kg/m^3, ρ_b=1450 kg/m^3; Кварцевый Sand ρ=2605 kg/m^3, ρ_b=1310 kg/m^3	Sodium Acetate (SA); Complex modifying additive (CMA)	w/c=0,41 Concrete composition, kg/m^3: Cement – 355 Aggregate: Crushed stone – 1266 Sand – 443 Water – 147 SA – 7 CMA – 20	– Compressive and Bending strength; – Porosity and Density.	ρ=2238 kg/m^3 P=38 % R_c=35 MPa R_b=1,93 MPa	–	[79]
19	Portland Cement	Dolomite fraction – 4,75–9,5 mm; Quarry Sand	Silica fume; Superplasticizer	w/c=0,25 Concrete composition, %: Sand – 18 Water – 0,36 Aggregate – 4 Silica fume – 7 Superplasticizer – 0,8	– Compressive strength, Density, Porosity.	ρ=2240 kg/m^3 P=17,02 % R_c=46,5 MPa	–	[63]
20	Portland Cement	Dolomite fraction – 4,75–9,5 mm	Silica fume (SF) (Microsilica 920-u); Hyperplasticiser on a polymer carboxylic ether (SP)	w/c=0,38 Concrete composition, %: SF – 7 SP – 0,8	– Density; – Compressive strength; – Porosity and Coefficient of water permeability.	ρ=2079 kg/m^3 P=16 % k=1,264 cm/s R_c: 7 days=22,0 MPa 28 days=24,3 MPa	–	[48]
21	Portland Cement 53 (MAHA GOLD)	Aggregate (quarry in Madukarai, Tamil Nadu, India) fraction – 12,5–20 mm ρ=2680 kg/m^3 ρ_b=1900 kg/m^3	Fly ash class F (Mettur thermal power plant, Tamil Nadu) particle size of 70-90 microns; Superplasticizer based PCE	w/c=0,3 a/c=4,4 Fly ash – 20 % by weight of cement/ Metakaolin/UFGGBFS – 10 % by weight of cement Superplasticizer – 0,167 % by weight of cement	– Density; – Abrasion Resistance on Los Angeles (LA) abrasion machine without steel balls; – Compressive strength; – Porosity and Coefficient of water permeability; – Sulphate Resistance.	ρ=2017,33 kg/m^3 P=28,66 % k=1,19 cm/s R_c=13,42 MPa	–	[24]
22			Metakaolin;			ρ=2103,15 kg/m^3		

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
			Superplasticizer based PCE			P=22,92 % k=0,81 cm/s R_c=15,1 MPa		
23			Ultra-Fine Ground Granulated Blast Furnace Slag (UGGBFS) particle size of 4-6 microns; Superplasticizer based PCE			ρ=1931,25 kg/m^3 P=24,84 % k=1,05 cm/s R_c=16,63 MPa		
24	Portland Cement CP II-F-32	Basalt fraction – up to 9,5 mm	–	w/c=0,34 Concrete composition, kg/m^3: Cement– 420 Aggregate – 1367 Water – 143	– The content of the powdery material and the water absorption of the aggregates by Brazilian standards NBR NM 46/2003; – Porosity; – Coefficient of water permeability by NBR NM 53/2003.	P=19,3 % k=0,497 cm/s	–	[25]
25		Доменный шлак fraction – up to 9,5 mm				P=24,8 % k=1,05 cm/s		
26		Clay brick from demolition waste fraction – up to 9,5 mm				P=27,1 % k=1,51 cm/s		
27		Recycled concrete aggregates fraction – up to 9,5 mm				P=23,4 % k=0,99 cm/s		
28	Portland Cement ASTM type I (OPC, 52,5)	Waste glass cullet fraction – 2,36–5 mm; Recycled concrete aggregate fraction – 5–10 mm	Silica fume (SF)	w/c=0,4 Concrete composition, kg/m^3: Cement – 272 Waste glass cullet – 755 Recycled concrete aggregate – 755 SF – 30	– Compressive strength; – Density, Porosity and Coefficient of water permeability; – Thermal conductivit;	ρ=1930 kg/m^3 P=26,7 % k=1,2 cm/s R_c=22 MPa λ=0,61 W/mK	Dry blending method	[26]
29	Portland Cement ρ=3130 kg/m^3	The raw recycled coarse aggregate, Granite	–	Concrete composition, kg/m^3: Cement – 359 Granite – 780	– Coefficient of brittleness and Modulus of elasticity; – Skid resistance (R); – Abrasion resistance;	P=20 % k=1,71 cm/s R_c=7,8 MPa R_b=2,2 MPa	–	[27]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
		fraction – 4,5–9,5 mm		The raw recycled coarse aggregate – 593 Water – 125	– Porosity and Coefficient of water permeability; – Compressive and Bending strength.	Coefficient of brittleness – 4,5 Модуль упругости – 11,8 GPa R=90 BPN Износ – 54,48 %		
30	Portland Cement, CEM II / A-M (S-V) 42,5 N	Dolomite GC 85/15 fraction – 8–16 mm; Sand GF85 (river Drava) fraction – 0–2 mm	–	w/c=0,33 Concrete composition, kg/m^3: Cement – 300 Water – 99 Aggregate – 1783,7 Proportions of aggregate,%: GC 85/15 – 90 GF85 – 10	– Porosity (two-dimensional X-ray images from X-ray computed microtomography); – Density; – Coefficient of water permeability; – Compressive and Bending strength.	ρ=1948 kg/m^3 P=27 % k=2,16 cm/s R_c=25,04 MPa R_b=2,41 MPa	–	[29]
31	Portland Cement (CEM I 42,5R) ρ=3150 kg/m^3	Limestone, Pumice fraction – 10–12 mm	–	w/c= 0,3 Concrete composition, kg/m^3: Cement – 420 Water – 126 Limestone – 1344 Pumice – 125,5	– Density, Porosity and Coefficient of water permeability; – Compressive, Tensile (R_t) and Bending strength.	ρ=1630 kg/m^3 P=20 % k=0,5 cm/s R_c=11,0 MPa R_t=1,35 MPa R_b=2,0 MPa	–	[30]
32	Portland Cement (type IP and GU)	Limestone Gravel fraction – 4,75–12,5 mm	Fly ash (FA); Nano-sized iron (NanoFe); Water-reducing admixture (WR)	a/c=4 Concrete composition, kg/m^3: Cement – 295 Water – 156 FA – 175 NanoFe – 30 WR – 6 Aggregate – 2000	– Compressive strength; – Coefficient of water permeability; – Water quality performance (pH, turbidity).	k=0,94 cm/s R_c=16,2 MPa pH=7 Turbidity – 1	–	[31]
33		Aggregate fraction – 2–6,3 mm	Chloride ions	Concrete composition, kg/m^3: Cement – 301	– Freeze-thaw durability; – Abrasion Resistance;	ρ=1930 kg/m^3 P=31,4 % k=2,25 cm/s	–	[32]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
	Portland Cement (OPC) CEM I 52,5 R	ρ=2716 kg/m^3; Shallow aggregate – The alluvial quartz sand – 0,4 mm;		Water – 111 Sand – 110 Aggregate – 1574 Chloride ions – 0,05 %	– Coefficient of water permeability; – Porosity and Density; – Compressive strength; – Leaching and clogging.	R_c=22,0 MPa		
34		Aggregate fraction – 2–6,3 mm ρ=2716 kg/m^3; Shallow aggregate – The alluvial quartz sand –0,4 mm; Seashell Crepidula (CR)/ Scallop (SC)/ Queen scallop (QS) fraction – 2–4 mm		Concrete composition, kg/m^3: Cement– 301 Water – 111 Sand – 110 Aggregate – 630 Chloride ions, % – 0,34/0,22/0,27 Seashell – 945		ρ=1925 kg/m^3 P=31,7 % k=2,25 cm/s R_c=19,0 MPa		
35						ρ=1860 kg/m^3 P=33,1 % k=3,0 cm/s R_c=18,5 MPa		
36						ρ=1810 kg/m^3 P=34,3 % k=3,4 cm/s R_c=15,5 MPa		
37	Portland Cement (OPC) type I	Limestone fraction – 6,3–9,5 mm; Sand	–	w/c=0,32 Concrete composition, kg/m^3: Water – 108,6 Cement – 339,5 Aggregate: Limestone – 1459,8 Sand – 146,0	– Coefficient of water permeability; – Porosity and Density; – Compressive strength.	ρ=1890 kg/m^3 P=23 % k=0,59 cm/s R_c: 7 days=11,5 MPa 28 days=14,5 MPa	–	[33]
38		Limestone fraction – 6,3–9,5 mm; Oil palm kernel shell (OPKS) fraction – 4,75–6,3 mm; Sand		w/c=0,32 Concrete composition, kg/m^3: Water – 108,6 Cement – 339,5 Aggregate: Limestone – 729,9 OPKS (4,75–6,3 mm) – 315,3 Sand – 146,0		ρ=1550 kg/m^3 P=23 % k=0,71 cm/s R_c: 7 days=5,6 MPa 28 days=8,5 MPa		
39		Limestone		w/c=0,32		ρ=1540 kg/m^3		

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
		fraction – 6,3–9,5 mm; Oil palm kernel shell (OPKS) fraction – 4,75–6,3 mm and 6,3–9,5 mm; Sand		Concrete composition, kg/m^3: Water – 108,6 Cement – 339,5 Aggregate: Limestone – 729,9 OPKS (4,75–6,3 mm) – 157,6 OPKS (6,3–9,5 mm) – 157,6 Sand – 146,0		P=25 % k=0,82 cm/s R_c: 7 days=6,0 MPa 28 days=9,1 MPa		
40	Portland Cement (OPC) type I	Granite fraction – 4,75–9,5 mm ρ=2720 kg/m^3 ρ_b=1294 kg/m^3; Oil palm kernel shell (OPKS) fraction – 4,75–9,5 mm ρ=1880 kg/m^3 ρ_b=732 kg/m^3;	–	w/c=0,3 Concrete composition, kg/m^3: Cement – 400 Granite – 958 OPKS – 662,14	– Density, Porosity and Coefficient of water permeability; – Compressive strength.	ρ=1436 kg/m^3 P=31 % k=0,55 cm/s R_c: 7 days=5,0 MPa 28 days=6,6 MPa	–	[36]
41	Cement	Gravel fraction – up to 10 mm	Polycarboxylate Superplasticizer Type I (SP); Viscosity modifying agent Type S (VMA)	w/c=0,3 Concrete composition, kg/m^3: Cement – 370 Gravel – 1398 Water – 111 SP – 3,7 VMA – 0,96	– Porosity and Coefficient of water permeability; – Compressive and Bending strength; – Mass Loss on Surface Abrasion.	P=16,9 % k=0,24 cm/s R_c=34,9 MPa R_b=3,04 MPa Mass Loss – 1,3 г	–	[37]
42	Portland Cement	Limestone (Hayes, Texas) fraction – 6,35 mm	–	w/c=0,33 Concrete composition, kg/m^3: Cement – 335 Aggregate – 1459,6 Water – 117,2	– Porosity and Coefficient of water permeability; – Compressive and Bending strength; – Cement paste thickness.	P=22,89 % k=0,72 cm/s R_c=16,4 MPa R_b=2,88 MPa Cement paste thickness – 4,76 mm	–	[38]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
43	Portland Cement, CEM II / A-M (S-V) 42,5 N	Dolomite fraction – 0–4 mm, 4–8 mm, 8–16 mm	Superplasticizer (SP)	w/c=0,33 Concrete composition, kg/m^3: Cement – 350 Water – 115,5 SP – 3,5 Aggregate: Dolomite (0–4 mm) – 813,6 Dolomite (4–8 mm) – 610,2 Dolomite (8–16 mm) – 610,2	– Porosity and Density; – Compressive and Bending strength.	ρ=2442,4 kg/m^3 P=6,3 % R_c=69,5 MPa R_b=9,7 MPa	–	[40]
44		Dolomite fraction – 4–8 mm, 8–16 mm; Sand (river Drava) fraction – 0–2 mm	–	Concrete composition, kg/m^3: Cement – 300 Water – 99 Aggregate: Sand (0–2 mm) – 178,4 Dolomite (4–8 mm) – 535,1 Dolomite (8–16 mm) – 1070,2		ρ=2076,6 kg/m^3 P=22,2 % R_c=26,6 MPa R_b=4,0 MPa		
45		Steel slag fraction – 4–8 mm, 8–16 mm; Sand (river Drava) fraction – 0–2 mm		Concrete composition, kg/m^3: Cement – 300 Water – 99 Aggregate: Sand (0–2 mm) – 205,3 Slag (4–8 mm) – 1232 Slag (8–16 mm) – 616		ρ=2435,4 kg/m^3 P=14,24 % R_c=26,5 MPa R_b=4,0 MPa		
46	Cement	Gravel; Sand	–	w/c=0,37 a/c=4,52 Concrete composition, kg/m^3: Cement – 335 Gravel – 1515	– Coefficient of water permeability, Porosity and Density; – Compressive and Bending strength;	ρ=1979 kg/m^3 P=19,2 % k=1,1 cm/s R_c=28,6 MPa R_b=4,0 MPa G=28,9 mm	–	[41]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
				Sand – 106 Water – 124	– Abrasion Resistance (G) and Freeze-thaw durability by NF EN 1338; – Skid Resistance (friction angle).	Friction angle – 89°		
47	Portland Cement CEM I 42,5 R	Aggregate fraction – 10–12,5 mm; Rubber crumb fraction – 4 mm	–	w/c=0,27 a/c=4,1 Concrete composition, kg/m^3: Cement – 450 Aggregate – 1275,2 Rubber crumb – 97,3 Water – 121,5	– Coefficient of water permeability; – Compressive and Tensile strength; – Abrasion Resistance; – Freeze-thaw durability (percent mass loss of concrete after 300 freeze-thaw cycles).	k=0,46 cm/s R_c=13,1 MPa R_t=1,5 MPa Mass Loss – 4,1 % Abrasion Resistance – 0,2 %	–	[42]
48	Portland Cement type II	Gravel fraction – 2,36–19 mm; Sand fraction – 4,75 mm	Rice husk ash (RHA); Superplasticizer (SP) of carboxylic ether (Glenium-110P, BASF); Glass fiber	w/c=0,4 Concrete composition, kg/m^3: Cement – 299,2 Gravel – 1395 Sand – 105 RHA – 40,8 SP – 4 Water – 135 Glass fiber – 0,2 % by volume of concrete mix	– Coefficient of water permeability; – Porosity; – Compressive, Tensile and Bending strength.	P=29 % k=0,47 cm/s R_c=23,5 MPa R_t=3,0 MPa R_b=4,0 MPa	Micro reinforcement with glass fiber	[43]
49	Portland Cement (OPC) CEM I 42,5 N	Aggregate fraction – 20 mm	–	w/c=0,34 Concrete composition, kg/m^3: Cement – 383 Aggregate – 1300 Water – 130	– Density; – Porosity and Coefficient of water permeability; – Compressive strength.	ρ=2133 kg/m^3 P=17,6 % k=0,3 cm/s R_c: 7 days=18,1 MPa 28 days=23,1 MPa	–	[44]
50	Portland Cement type I	Limestone; Shallow aggregate	Latex; Water-reducing admixture (HRWR); Airentraining agent (AEA);	Concrete composition, kg/m^3: Cement – 360 Limestone – 1440 Shallow aggregate – 100 Water – 95	– Coefficient of water permeability and Porosity; – Compressive and Bending strength; – Freeze-thaw durability by ASTM C666;	P=24 % k=0,2 cm/s R_c=47,5 MPa R_b=2,3 MPa Mass Loss – 15 %	–	[45]

No.	Concrete composition: Types of Binder	Type of aggregate	Functional Additives	Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
			Viscosity modifying agent (VMA)	Latex – 36 HRWR – 940 мл AEA – 690 мл VMA – 500 мл	– Abrasion Resistance by ASTM C 131.			
51	Portland Cement type I	Aggregate fraction – 3–8 mm, 8–15 mm ρ=2680 kg/m^3; Sand ρ=2540 kg/m^3	Superplasticizer (SP)	w/c=0,44 Concrete composition, kg/m^3: Cement – 335 Aggregate: 3–8 mm – 480 8–15 mm – 720 Sand – 618 SP – 2,45 Water – 95	– Compressive strength.	R_c=62,1 MPa	–	[84]
52	Portland Cement PO 32,5	Limestone, Diabase fraction – 2,36–26,5 mm	Fly ash (FA)	w/c=0,41 Concrete composition, kg/m^3: Cement – 145 FA – 36 Aggregate – 1625 Water – 82	– Compressive strength; – Abrasion Resistance (DL / T5150-2001); – Shrinkage.	R_c: 7 days=9,0 MPa 28 days=16,5 MPa Mass Loss – 18 %	–	[65]
53	Portland Cement	Aggregate fraction –5,0–13,0 mm	Water-soluble cellulose based polymer powder (P) ρ=2400 kg/m^3; Superplasticizer (SP)	w/c=0,3 Concrete composition, kg/m^3: Cement – 370 Aggregate – 1398 Water – 111 P – 0,96 SP – 3,7	– Coefficient of water permeability and Porosity; – Compressive and Bending strength; – Slump (JIS A 1150); – Apparent density and compaction index.	P=21 % k=1,4 cm/s R_c=20,0 MPa R_b=4,0 MPa	–	[68]
54	Portland Cement type I CEM I 42,5H	Granite crushed stone fraction – up to 10 mm	Fly ash ρ_b=1000 kg/m^3 ρ=2305 kg/m^3; Superplasticizer (MELFLUX 5581) 29 %	Concrete composition, kg/m^3: Cement – 220 Fly ash – 60 Aggregate – 1230 Superplasticizer – 1,96 Water – 90,0	– Coefficient of water permeability; – Porosity; – Compressive strength.	P=15,4 % k=0,48 cm/s R_c=11,3 MPa		[76]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
55	Cement	Granite crushed stone fraction – 5–20 mm	–	c/a=1/5	– Coefficient of water permeability; – Compressive strength.	k=1,5 cm/s R_c=21 MPa		[78]
56	Portland pozzolana cement grade OPC-53	Aggregate fraction – 12,5–6 mm	Water reducing agent for the pervious concrete generally styrinebutadien	Concrete composition, %: Cement – 1 Water – 0,36 Aggregate – 4	– Coefficient of water permeability; – Compressive and Bending strength.	k=0,69 cm/s R_c: 7 days=18,7 MPa 21 days=24,9 MPa 28 days=26,9 MPa R_b=3,5 MPa	–	[61]
1.2. Based on cement with the use of a Polymer binder								
57	Portland Cement R_c= 42,5 MPa 10% Silane Polymermixture emulsion	Crushed concrete, Clay brick from demolition waste fraction – 5–10 mm CWi=24,1 % ρ_b=1230 kg/m^3 ρ_a=2540 kg/m^3	–	w/c=0,34 a/c=3,0 Concrete composition, kg/m^3: Cement – 464 Aggregate – 1392 Water – 157,76	– Membrane-forming ability for measuring the thickness of cement paste adhered to the surface of the aggregate (τ, MPT); – Connected porosity with drainage method (CJJ/T 252-2016); – Density; – Apparent and Bulk density; – Crush index; – Water absorption; – X-ray micro-tomography.	ρ=1430 kg/m^3 W=2,25 % τ=0,154 MPT=0,16 mm	Immersion of the aggregate in a 10% solution of a silane polymer emulsion for formation hydrophobic silicone membranes on the surface the aggregate acting as alkaline substrates, removing the aggregate and drying it, followed by mixing the remaining components of the mixture.	[9]
58	Cement (CEM 132,5 R)	Aggregate fraction – 4–8 mm	–	w/c=0,26 Concrete composition, kg/m^3:	– Porosity;	P=20 % R_c=27,1 MPa R_b=5,8 MPa	–	[54]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
	Polymeremulsion			Cement – 300 Water – 78 Polymeremulsion – 20% by weight of cement	– Compressive and Bending strength.			
59	Portland Cement type I (OPC) Styrene-butadiene latex	Crushed Gravel fraction – 16–19,5 mm; Sand	Water-reducing admixture; Thickening agent	w/c=0,34 Concrete composition, kg/m^3: Cement – 400 Aggregate: Shallow – 224 Coarse – 1692 Latex – up to 7% of concrete mix	– Coefficient of water permeability and Porosity; – Bending strength three-point method (ASTM C 78); – Tensile strength (ASTM C 496); – Abrasion Resistance after 28 days curing (IS: 2386 part – 4).	P=33,46 % k=0,876 cm/s R_c: 7 days=11,6 MPa 28 days=16,5 MPa 56 days=23,57 MPa Mass Loss – 4,96 %	–	[20]
60	Portland Cement Redispersible polymer powder (RPP) based styrene butadiene rubber (SBR)	Crushed Granite fraction – 5–20 mm; Recycled concrete aggregate fraction – 5–22 mm	–	w/c=0,3 polymer/c=0,5 Concrete composition, kg/m^3: Cement – 260 Water – 78 Aggregate – 1542 Polymer– 130	– Porosity; – Coefficient of water permeability; – Compressive strength (JIS A 1106).	P=24 % k=0,31 cm/s R_c=14,8 MPa	–	[62]
61	Portland Cement (type P.O. 42,5, China) Polymer (mixture of acrylic and polycarboxylic emulsion) (Hebei, China)	Limestone fraction – 27,5 mm, 32,5 mm, 37,5 mm	Polycarboxylate Superplasticizer	w/c=0,32 a/c=6 Concrete composition, kg/m^3: Cement – 274 Water – 87,69 Aggregate – 1644 Polymer– 8,77	– Porosity; – Compressive and Bending strength.	P=30,6 % R_c=16,4 MPa R_b=1,6 MPa	–	[34]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
62	Cement Water-based ethylene-vinyl acetate (EVA) emulsion	Limestone fraction – 4,75–12,5 mm; River Sand	Polypropylene (PP) fibers; Airentraining agent (AEA); Superplasticizer (SP)	w/c=0,25 Concrete composition, kg/m^3: Cement – 350 Water – 70 Aggregate – 1433 Sand – 86 AEA – 0,035 EVA – 42 PP – 0,70 SP – 0,88	– Effective Porosity by vacuum sealing method (ASTM D7063); – Compressive and Bending strength; – Freeze-thaw durability by GB / T 50082-2009 (coefficient of strength (k_R)).	P=15 % R_c: 7 days=12 MPa 14 days=16,8 MPa 28 days=19,5 MPa R_b=1,9 MPa k_R=50 %	–	[35]
63	Cement Latex emulsion	Granite fraction – 5–20 mm;	–	w/c=0,3 Concrete composition, kg/m^3: Cement – 283 Latex – 14 Water – 85 Aggregate – 1620	– Porosity; – Coefficient of water permeability; – Compressive and Bending strength.	P=22 % k=2,5 cm/s R_c=15,5 MPa R_b=3,8 MPa	–	[64]
64	Cement Redispersible polymer powder (RPP) based styrene butadiene rubber (SBR)	Recycled aggregate that was made by crushing waste concrete fraction – 5–22 mm	–	w/c=0,3 Concrete composition, kg/m^3: Cement – 260 RPP – 13 Water – 78 Aggregate – 1542		P=25 % k=3,1 cm/s R_c=14,0 MPa R_b=3,2 MPa		
65	Portland cement type I Latex styrene-butadiene rubber (SBR)	Limestone fraction – 9,5 mm; Sand (Tennessee River)	–	Concrete composition, kg/m^3: Cement – 306,9 Latex – 30,7 Water – 91,3 Aggregate – 1381,2 Sand – 96,7	– Porosity; – Coefficient of water permeability; – Compressive and Bending strength.	P=27 % k=1,5 cm/s R_c=12,1 MPa R_b=1,5 MPa	–	[46]
66	Portland cement (P.O 42,5)	Coarse aggregate fraction – 2,36–4,75 mm;	–	Concrete composition, kg/m^3: Cement – 300	– Porosity; – Coefficient of water permeability;	P=20,8 % k=0,612 cm/s	–	[67]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
	(Huaxin Cement Company Ltd.) Styrene-Butadiene Latex SD623 (Shanghai BASF Dispersions Co. Ltd.)	Shallow aggregate fraction – 2,36–4,75 mm; Rubber aggregate: A – 1,18–4,75 mm; B – 0,6–2,36 mm		Latex – 96 Water – 48 Aggregate: Coarse – 1476 Shallow – 200–140 Aggregate replacement ratio by volume,%: A – 18 B – 0–30	– Abrasion Resistance; – Impact resistance; – Microstructure of rubber concrete.			
1.3. Based on a polymer or organo-polymer binder								
67	Polyester resin	Aggregate fraction – 4,75–9,5 mm ρ=3150 kg/m^3	–	Concrete composition, kg/m^3: Polymer– 251 Aggregate – 1570	– Coefficient of water permeability and Porosity; – Freeze-thaw durability (Compressive strength after 50 freeze-thaw cycles, reduced strength); – Compressive strength.	P=20,4 % k=0,89 cm/s R_c=79,3 MPa $R_{c\ \text{after 50 freeze-thaw cycles.}}$=78,2 MPa Strength reduction=1 %	–	[17]
68	Styrene-butadiene-styrenenmodified asphalt binder (SBS) ρ=1320 kg/m^3	Basalt fraction – <16 mm ρ=1284 kg/m^3	Limestone filler (LF) ρ=2699 kg/m^3; Activated carbon particle size – 0,074 mm ρ=1702 kg/m^3	Modified asphalt binder – 5.64% by weight of aggregate Filler – 4 % by weight of aggregate (mineral filler – 30 %, activated carbon – 70 %)	– The water quality of runoff according to six Indicators, including physico-chemical indicators (suspended solids content, turbidity and pH value), heavy metal pollution index (Zn and Pb); – The effect of activated carbon content and bulk properties of the sample (content and thickness of air voids) on the filtration characteristics of porous asphalt concrete; – Abrasion Resistance for assessing particle loss resistance (Gi) according to JTG E20 T0733;	P=24 % S_M=9,03 кН G_i=4154 passes/mm pH=6,78 Removal rate: Zn=20 % Pb=5 %	–	[58]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
					– The Schellenberg binder drainage by (JTG E20 T0732); – Moisture resistance (JTG E20 T0729); – Marshall stability (SM) in accordance with JTG F40-2004; – Porosity; – Rutting depth.			
69	Polymer modified bitumen with butadiene styrene (SBS) ρ=1000 kg/m^3	Sandstone, with a quartz content of 20-30% ρ=2700 kg/m^3	–	Binder - 4.63% of the total weight of the mixture	– Porosity; – Abrasion Resistance; – Microtomography; – Neutron radiography imaging to study the distribution and movement of water.	P=22,2 %	–	[59]
2. CONCRETE FOR FILTRATION AND DRAINAGE SYSTEMS								
2.1. Based on cement without the use of a Polymer binder								
70	Portland cement R_c=42,5 MPa	Expanded clay fraction – 9–12 mm	Fly ash (FA); 3-thiocyanatopropyltriethoxysilane (TCPS); Polycarboxylate Superplasticizer	w/c=0,3 Concrete composition, kg/m^3: Cement – 373 Aggregate – 1469 T-FA (FA+ TCPS) – 4% of the total weight of cement	– Porosity; – T-FA and its influence on the sequestering cadmium (Cd (II)) in the solution; – The concentration of Cd (II) in the solution with submerged prepared permeable concrete.	P=24,9 %	Filtering constructions. Preparation of granules from fly ash (FA) by its modification with 3-thiocyanatopropyltriethoxysilane (TCPS), alkaline activation of granules and their inclusion in the concrete mix.	[11]
71	Portland cement	Granite fraction – 9,5 mm	Fly ash класса F (FA);	w/c=0,27	– Porosity; – pH of wastewater;	P=25 % pH=9	–	[12]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
	(CEM I 52,5R)		Superplasticizer (SP) Chryso Fluid Premia 310	Concrete composition, kg/m^3: Cement – 330 Granite – 1890 FA – 140 SP – 9,2 Water – 130	– Hydration of cement and interaction with waste water; – Mineralogical analysis of water passed through concrete; – Concentrations of Na, Mg, K, Ca, Cr, Mn, Fe, Co, Ni, Cu, Zn, Al, Rb and Sr using PerkinElmer SCIEX.			
72	Blast furnace slag cement (blast furnace slag powder content: 30%) ρ=3020 kg/m^3	Crushed concrete; Recycled aggregate that was made by crushing waste concrete (RA) fraction –5–13 mm	Granular artificial zeolite (Ze) (ρ=1900 kg/m$^{3)}$; Silica fume (SF); Glass fiber (GF) (10 mm, ρ=2780 kg/m^3); Superplacticizer of lignin sulfonate series (SP) ρ=1200 kg/m^3, pH 7–9, (solid content of 41–45%)	Concrete composition, kg/m^3: Cement – 265 Crushed concrete – 1270 RA – 368 Ze – 29 SF – 29 GF – 7,9 SP – 3,17 Water – 73	– Porosity; – Coefficient of water permeability; – Compressive strength; – Filtration ability.	P=20 % k=1,4 cm/s R_c=16,0 MPa	–	[57]
73	Portland cement grade 53	Aggregate fraction – ≤0,3 mm; 0,3–1,18 mm; 1,18–2,36 mm; 2,36–4,75 mm; 4,75–6,3 mm	Polycarboxylic Ether Superplasticizer (PSE)	w/c=0,32 a/c=4 The proportion of concrete mix,% by weight of cement: PSE – 0,5 Aggregate: ≤0,3 mm – 5 0,3–1,18 mm – 5 1,18–2,36 mm – 20 2,36–4,75 mm – 25 4,75–6,3 mm – 45	– Coefficient of water permeability by falling head, coefficient of permeability by Darcy's law; – Porosity (3-dimensional X-ray computed tomography); – Leachability; – Removing lead from leaking water.	P=15,53 % k=2,0 cm/s	–	[28]
74	Cement CEM II / A-L 42.5R	Limestone fraction – 5–12 mm	Retarder	w/c=0,29 Concrete composition, kg/m^3: Cement – 400	– Coefficient of water permeability; – Compressive strength.	k=1,6 cm/s R_c=10,0 MPa	–	[47]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
				Aggregate – 1400 Retarder – 1% by weight of cement				
3. DECORATIVE CONCRETE WITH ORGANIC VEGETABLE LAYER								
3.1. Based on cement without the use of a Polymer binder								
75	Cement	Aggregate fraction – 6–10 mm	White cement/ Metakaolin/ Limestone filler; Superplasticizer	Concrete composition, kg/m^3: Cement – 179,5 Aggregate – 1570,9 Metakaolin – 82,5 Limestone filler– 41,2 Superplasticizer – 3,9 Water – 91	– Seed germination and seedling development in greenhouse conditions; – Chemical analysis irrigation water specimen to measure pH, cations, and anions (SiO2, Al2O3, Fe2O3, CaO, MgO, K2O, Na2O, SO3, P, Cl and NO3) every 2 h for the first day, three times/day for the first week, and once/day thereafter, for four weeks; – Adhesion of the layer of permeable concrete with the supporting part of the wall.	ρ=1700 kg/m^3 P=32 % $R_{c=}$10 MPa A=1,9 MPa	"Living" walls. Vertical casting using standard formwork.	[2]
76	Portland cement (Tangshan, China) R_c= 42,5 MPa	Mixture of limestone and gravel (Beijing, China) fraction – 10–25 mm $ρ_a$=2780 kg/m^3 CWi=8,5 %	Blast furnace slag ρ=2890 kg/m^3; Fly ash class 1F; Polycarboxylic acid water-reducing admixture; Biochar 92,4% C (fraction – 1–10 mm)	Concrete composition, kg/m^3: Cement – 216,7 Aggregate – 1599,84 Fly ash – 26 Slag – 52 Biochar – 5 Water-reducing admixture – 1,45 Water – 87,78	– Coefficient of water permeability by method put forward in Gong's research; – Porosity; – Compressive strength; – Apparent density; – Crush index; – Plant growth test.	P=24,9 % k=1,66 cm/s R_c=16,87 MPa Germination rate =84 %	"Living" slabs, which include biochar - an additive to improve soil fertility.	[3]
77	Sulfoalumina te cement (SAC) ρ=2810 kg/m^3 (Jining Zhonglian	Ceramsite fraction – 16–19 mm Bulk density – 452 kg/m^3 CWi=55,3 %	Water reducing agent; Retarder	w/c=0,25 Concrete composition, kg/m^3: SAC – 231,3 Ceramsite – 410,7	– Coefficient of water permeability; – Porosity; – Compressive strength; – Apparent density; – Crush index;	ρ=705 kg/m^3 P=33,66 % k=3,85 cm/s $R_{сж}$: 1 day=2,9 MPa 3 days=4,3 MPa	"Living" Support Walls	[4]

No.	Concrete composition			Mixing Ratio	Functional properties of drainage concrete	Physico-mechanical properties of the material	Notes	Source Link
	Types of Binder	Type of aggregate	Functional Additives					
	Cement Co., Ltd. (China))			Water reducing agent – 2,5 Retarder – 0,9	– Alkalinity of the vegetated concrete is measured according to the method by L and pH measurement; – The nitrogen and phosphorus release rates in water (the fertilizer release of vegetated concrete).	28 days=5,7 MPa		
3.2. Based on cement with the use of a Polymer binder								
78	Sulfoaluminate cement (SAC) grade 42,5 R (Special Cement Co., Ltd of Qufu, China) Polycarboxylate Polymer(PP) (Shandong Academy of Building Research, China)	Crushed limestone rubble ρ=2730 kg/m^3 CWi=9,3 %; Waste demolition concrete ρ=2590 kg/m^3 CWi=18,3 %	Urea ($CO(NH_2)_2$; Diammonium phosphate (DP,$(NH_4)_2HPO_4$); Boric acid (BA) (Sinopharm Chemical Reagent Co., Ltd, China)	w/c=0,25 Concrete composition, kg/m^3: SAC – 220 Aggregate – 1320 BA – 0,87 PP – 2,39 Water – 55	– Soil washout resistance (SWR) in accordance with Zhou et al., 2010; – Coefficient of water permeability under a water head of 150 mm over a period of 50 s; – Porosity; – Compressive strength.	P=35% k=2,95 cm/s R_c=8,4 MPa	Protecting slopes along motorways and river banks	[5]

carbonate sedimentary (limestone) and aluminosilicate intrusive (granite) rocks are distinguished. The main controlled parameters during the evaluation of the effectiveness of highly permeable concrete include porosity of products, compressive strength and water permeability coefficient.

Conclusion

This review article presents the analysis of the research results of numerous authors working in the direction of the optimization of compositions and search for technological solutions in order to improve the performance of highly permeable concrete, as well as expand the areas of their use. The accumulated empirical material made allowed generalizing and structuring the available data according to such criteria as the type of binder used, the genetic type of rocks used to obtain large aggregate and the type of functional additives. The analyzed physical and mechanical properties of concrete developed by various scientific groups allowed deriving the boundary values of porosity, strength and water permeability coefficient for concrete for various functional purposes – road and sidewalk pavements, filtration and drainage systems, decorative concrete with an organic plant layer.

In connection with the expansion of the areas of use of drainage concrete, and taking into account the fact that all the functional areas of the use of highly permeable concrete are more or less related to liquid percolation, which, during the evaluation of the properties of such varieties of concrete, entails a change in the chemical composition of the irrigation water passing through the concrete and pH environment, the following tasks, designed to provide increased durability of materials still remain relevant and open:

– increase of resistance to aggressive influences of the operating environment, as well as the development of highly permeable composite (multicomponent) materials with prolonged corrosion resistance;

– optimization of the structure of the pore space in order to minimize clogging of the pores and increase the timing of the drainage function of materials;

– optimization of concrete composition in order to increase the mechanical and chemical filtration capacity.

The analysis of the existing problems allowed identifying the following ways to achieve the effectiveness of highly permeable concrete: the first is aimed at the increase of the contact area between the aggregate particles without reducing the total porosity of the concrete; the second one is aimed at the increase of the strength of the cement matrix and its adhesion to aggregates; the third one reduces the amount of soluble components in concrete.

These problems can be solved through the use of a complex of methods and approaches that are quite traditional for construction materials science. However, during the application of those methods it is necessary to take into account the specifics of the target functions facing products from highly permeable concrete such as:

– the choice of rational genetic types of rocks and industrial wastes that will satisfy the requirements as raw materials to obtain large aggregate for: water resistance; the ability to provide a given shape and surface morphology of the aggregate grains during crushing or in its natural form (for example, sedimentary clastic rocks); surface activity in relation to the binder to ensure its maximum possible adhesion; if necessary, to enhance the filtration function by sorption capacity;

– optimization of the grain composition of the aggregate, which includes: selection of the minimum possible strenght density of particles of coarse aggregate; determination of the rational shape and surface morphology of the aggregate particles in order to comply with the strength density requirement;

– optimization of the mineral composition of the matrix composite binder – a type of binder and active mineral components;

– the use of various types of additives such as: water-reducing in order to increase the water resistance of cement stone, composing thin layers in the intergranular space of a large aggregate; active additives providing resistance to chemical and biocorrosion processes; components that increase adhesion.

There is no doubt, that all the above methods and approaches must comply with technical and economic criteria for the effectiveness of the use of certain materials, taking into account the regional specifics of the mineral resource base.

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